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The Role of Common Carotid Artery End-diastolic Velocity in Near Total or Total Internal Carotid Artery Occlusion

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Objectives: *To evaluate the role of the end-diastolic velocity (EDV) in the common carotid artery (CCA) as a marker of internal carotid artery (ICA) occlusion.*
Design: *Validation of retrospective data in a prospective clinical study.*
Methods: *The EDV in 94 patients with total ICA occlusion and in 24 patients with high grade (95–99%) unilateral ICA stenosis identified on extracranial carotid colour-flow Duplex imaging (CFDI) and arteriography was reviewed, and was retrospectively compared to the EDV of 176 normal individuals. Identification of patients with ICA occlusion was most accurate (99.3%) with an ipsilateral EDV ≤ 12cm/s and a DIFF ≥ 10cm/s (DIFF = contralateral EDV – ipsilateral EDV). These values were then prospectively applied to all 886 patients (67 with high grade stenosis or occlusion) who underwent CFDI at our institution during 1994.*
Results: *The EDV ≤ 12 had a 92% sensitivity, a 99.4% negative predictive value (NPV) and a 85% specificity in distinguishing between occluded and patent ICA's. In combination with a DIFF ≥ 10 was 80.4% sensitive and 97.5% specific. The positive predictive value of the EDV ≤ 12 in the distinction between 95–99% ICA stenosis and ICA occlusion was 78.3%, and that of the combination was 85.4%. The EDV was rarely zero and 10% of patients with normal or minimally diseased ICA's had an EDV ≤ 12 and/or a DIFF ≥ 10.*
Conclusions: *The EDV ≤ 12cm/s is a sensitive marker of ICA occlusion with a high NPV and in combination with the DIFF ≥ 10cm/s, is specific. Nevertheless, EDV parameters are inaccurate in the distinction of 95–99% ICA stenosis from occlusion. Low EDV can be found in a number of patients with minor or no ICA disease, particularly in those with a stroke or silent cerebral infarct.*

Key Words: Internal carotid artery occlusion; Common carotid artery; End-diastolic velocity.

Introduction

Carotid bifurcation ultrasonography has recently been promoted as the only method in the management of patients with extracranial carotid artery disease.[1–3] If not so, at least it is regarded extremely useful in identifying the minority of patients who need arteriography.[4] The high accuracy of Duplex ultrasonography to detect and grade stenoses, especially those greater than 50%, is very convenient clinically.[5–7] However, whether the clinical impact of the method is preserved or not in distinguishing subtotal (95–99% diameter stenosis) from total occlusion of the internal carotid artery (ICA), still remains a challenge. This distinction is essential, for operation is only rarely indicated on chronic carotid occlusion.[8] Colour-flow Duplex imaging (CFDI) enriched with the "slow-flow" technology seems to effectively eliminate such inaccuracies.[6,7,9,10] Numerous findings of both conventional duplex and CFDI have been correlated with the advent of ICA occlusion.[11–13] Of the indirect ones, "externalisation" of the common carotid artery (CCA) flow waveform on the affected side has been implied, with steep upstroke in systole and flow to zero during diastole, reflecting increased vascular resistance and altered haemodynamics.[11, 14–17] This is in contrast with the contralateral CCA which maintains flow in diastole, if it supplies a less severely stenosed ICA (asymmetry).[11,17] Nevertheless, there has not been neither clear definition of "flow to zero" and externalisation -in terms of absolute numerical values of end-diastolic velocity in the ipsilateral CCA (EDV)-nor of flow asymmetry between the two CCAs (DIFF =

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contralateral CCA end-diastolic velocity minus ipsilateral EDV). More so, it remains unclear whether flow to zero means that EDV is actually zero. The present study was conducted to investigate the value of EDV as measured by CFDI, in the detection of 95–99% ICA stenosis or total ICA occlusion.

Patients and Methods

We reviewed all diagnoses of higher than 95% unilateral ICA stenosis (including unilateral occlusions) in patients who had undergone both CFDI and cerebral arteriogram at St. Mary's Hospital from 1991 to 1993. Velocity data from both CCAs were evaluated in patients in whom both tests agreed perfectly, as well as in 176 normal individuals. Cut-off points of ipsilateral CCA-EDV ≤ 12 cm/s and DIFF ≥ 10cm/s were found the best to identify patients with greater than 95% ICA stenosis. In order to validate these values, we then prospectively tested them in all 886 patients that were examined by CFDI at our institution during 1994. The data were analysed to determine their prevalence and their impact on diagnosis of ICA severe stenosis or occlusion, as made by CFDI.

Retrospective study

The reports of all 2978 patients who were examined by CFDI since early 1991 and up to the end of 1993 were reviewed. Ultrasonic diagnosis of unilateral 95–99% ICA stenosis or occlusion was made in 177 patients during that period. These 177 patients were then matched with all individuals who had been subjected to cerebral angiography at our institution during the same time period. Only patients who had both tests done within 30 days were selected for the study. Cases with poor quality arteriograms (4 patients), with severe innominate artery (1 patient) or proximal CCA stenosis (3 patients), CCA dilatation (1 patient), and unusual anatomic variations of carotid vessels (4 patients) were all excluded. Thus, 131 patients were available for the study. Velocity data were finally analysed in 24 patients with unilateral 95–99% ICA stenosis (18 men, 6 women, mean age 64.4 years, range 58–84) and in 94 patients with unilateral ICA occlusion (63 men, 21 women, 66.8 years, range 43–83), in whom both methods agreed perfectly. Unilateral 95–99% ICA stenosis or occlusion meant that the contralateral ICA was less than 95% stenosed i.e. from 0% to 95%.

CCA-EDV of the ipsilateraal to 95–99% or 100% ICA stenosis side as well as DIFF were assessed in all patients. The same EDV variables were evaluated in 176 normal individuals (111 men, 65 women, 64.5 years, range 22–94). The cohort of the normal group was consisted of hospital staff members, their relatives and vascular patients' relatives. Their age and sex were similar to those of patients who had near total or total ICA occlusion. Selection was based only on their history, possibly excluding the presence of any clinically apparent systemic disease such as diabetes, cerebrovascular, cardiovascular, kidney, lung, liver or collagen disease. Those receiving vasoactive or antihypertensive drugs were also excluded. A normal scan was a prerequisite for entry in the study and meant a less than 15% diameter stenosis in any extracranial carotid artery, with no abnormalities suspected in any other detectable vessel as well.

Scattergrams were constructed plotting EDV and DIFF for all three groups as well as EDV against DIFF. Total ICA occlusion correlated best with ipsilateral CCA EDV ≤ 12 cm/s and with DIFF ≥ 10cm/s. No worthwhile cut-off point could define patients with 95–99% from those with total ICA occlusion.

Prospective study

Study patients consisted of all 886 individuals that were examined at our laboratory in 1994. CFDI velocity data from all the CCAs were distributed against different degrees of ICA stenosis, which were determined using standard CFDI criteria. Follow-up patients who progressed in ≥ 95% ICA stenosis, patients with undefined vessels, with carotid dissection, with severe CCA disease, and post -carotid surgery patients were excluded from analysis. Finally, 802 patients were available for evaluation. Sixteen patients were found to have 95–99% ICA stenosis and 51 occlusion by CFDI; Demographics and medical history were also reviewed.

Ultrasonography

A Hewlett-Packard Sonos 1500 computed sonographic system with a 4.5/5.5 MHz linear array transducer (5 MHz pulsed Doppler) was used for scanning all patients, in both studies, with the same examination technique. Three doctors and three sonographers with special training in cerebrovascular scanning were performing the tests in a random rota during the study period using a standard protocol. They were unaware of the cut-off points settled in the retrospective study, thus avoiding biased measurements during 1994. Patients were examined in the supine position after some minutes of relaxing. Both cross-section and longitudinal views of carotid vessels were typically obtained from all testable sites in the neck, from the most proximal CCA to the more distal ICA. Subclavian and vertebral arteries were also examined. Pulsed Doppler measurements were obtained at 60° insonation angle. The smallest possible sample volume was usually placed at midstream and parallel to the vessel lumen. Velocities in the CCAs were measured at their distal third (usually within 2 cm from the carotid bulb); in the ICA, at the assumed point of maximal stenosis, as well as proximal and distal to that point. EDV was measured just before the systolic upstroke of the following pulse, at the upper part of the spectral line. In the presence of artrial fibrillation or other arrhythmia, 10 consecutive measurements were made for either systolic or diastolic velocities and the average was taken into account. Velocities picked up in tortuous or kinked sites were not encountered. The same criteria were used for grading ICA stenosis in both studies (Table 1).

The diagnosis of occlusion was made when spectral or colour Doppler flow could not be obtained from the well visualised ICA on B-Mode imaging, while at the same time the ECA had been clearly identified. Tapping of the ipsilateral temporal artery for delineation of ECA and its branches is routinely used at our laboratory. The presence of echogenic material filling the lumen in a subnormal sized vessel lacking of arterial pulsations and the presence of reversed flow just before the obstruction (stump or "blue cup"), were helpful cofeatures. Additional findings that helped alerting the examiner to the presence of a high-grade ICA stenosis or occlusion included: (a) dampened ipsilateral CCA flow velocities relative to the contralateral ones ("externalisation" of the CCA), (b) low resistance ECA flow waveform, and (c) increased relative ECA caliber ("internalisation" of the ECA). When occlusion was suspected, the instrument was adjusted for the slowest pulse repetition frequency (PRF) in a decreased colour sampled area and at the highest possible receiver colour gain so not to produce extreme artifacts. Care was taken to scan in many angles so that insonation angle not to be perpendicular to flow. The pulsed Doppler sample was enlarged to cover the whole suspected area and sampling was obtained at high gain and at high power output with the wall filters set to minimum. Special care was taken to avoid reporting baseline artifacts as dampened flow.

The diagnosis of 95–99% ICA stenosis was made when trickle flow by pulsed Doppler (very low and dampened velocity, lacking of pulsatility) or by colour Doppler (flashes of colour or string flow along the course of the ICA) was detected under the "slow-

Table 1. Doppler criteria for grading 0–95% internal carotid stenosis[18]

Diameter Stenosis (%)	Velocities	Flow characteristics
0–15	PSV<125cm/s	Minimal/no spectral broadening during systolic deceleration. Window present above the level of EDV. No turbulence (white areas) on CDFI. Colour fills the entire vessel lumen, thus excluding undetected on B-mode echolucent areas. Flow reversal at the bulb (boundary layer separation) in normals.
16–50	PSV<125cm/s	Spectral broadening during systole. No window present above the level of EDV. Turbulence on CDFI. Colour column compatible with less than 50% stenosis.
51–70	PSV>125cm/s, *and* EDV<100cm/s, *and* R<15	Marked spectral broadening. Turbulence on CDFI.
71–90	PSV>125cm/s, and 30>R>15 (When EDV>135cm/s and/or PSV>240cm/s, the stenosis is above 80%)	Marked spectral broadening. Turbulence on CDFI.
91–95	PSV>240cm/s, *and* EDV>135cm/s, *and* R>30	Marked spectral broadening. Turbulence on CDFI.
95–99	Dampened flow, almost continuous	Detectable Doppler shift. Strings of colour or fluctuating flow. Re-establishment of antegrade ICA flow at a higher level.
Occlusion	No flow at all	No flow at all, despite the use of slow or venous flow machine settings.

PSV: Peak systolic velocity in ICA (at the point of maximal stenosis).
EDV: End-diastolic velocity in ICA (at the point of maximal stenosis).
R: PSV in ICA to end-diastolic velocity in ipsilateral CCA Ratio (PSV-ICA/EDV-CCA).
When EDV is between 100 and 135cm/s then the stenosis is likely to be 70–80%.

flow" adjustments of the scanner. In these cases, flow was reconstituted in the distal cervical ICA, without or with minimal pulsatility.

Grading of stenoses relied on a combination of velocity criteria that we have been using in recent years (Table 1). The ratio of peak systolic velocity measured at the presumed more stenotic site of the ICA to the EDV in the CCA was the principal way of estimating > 50% ICA stenosis, as the diagram of that ratio against the angiographically derived grade of stenosis depicted.[18]

Arteriography

Although most requests at our institution in the evaluation of carotid vessels are intra-venous digital subtraction arteriograms (IV DSA), in the presence of a very tight ICA stenosis or occlusion an intra-arterial DSA (IA DSA) with aortic arch or selective injections is usually performed. Only patients that were evaluated by IA DSA, either selective or unselective but with clear cut findings obtained from at least two projections, were taken into account in both parts of this study.

Carotid arteriograms of all study patients were reviewed by experienced radiologists. The diagnosis of ICA occlusion was made when the contrast column terminated at the site of obstruction. The diagnosis of 95–99% ICA stenosis (slim or string sign) was made when a string of contrast was passing antegradely through the vessel in delayed projections at the time that the CCA, the ECA and its branches had been already filled with contrast.

Results

Retrospective study

In order to assess the minimum overlap of EDV variables between 176 normal individuals, 24 patients with 95–99% ICA stenosis and 94 patients with ICA occlusion, three scattergrams were constructed:

Figure 1 shows the distribution of ipsilateral EDV in the three groups. EDV ≤ 12 cm/s was found to be the best cut-off value distinguishing patients with ICA occlusion from the control group, as a minimum of 14 false positive (FP) and six false negative (FN) results were produced by this selection. It was clear that patients with 95–99% stenosis could not be discriminated from those with occlusion, in terms of EDV.

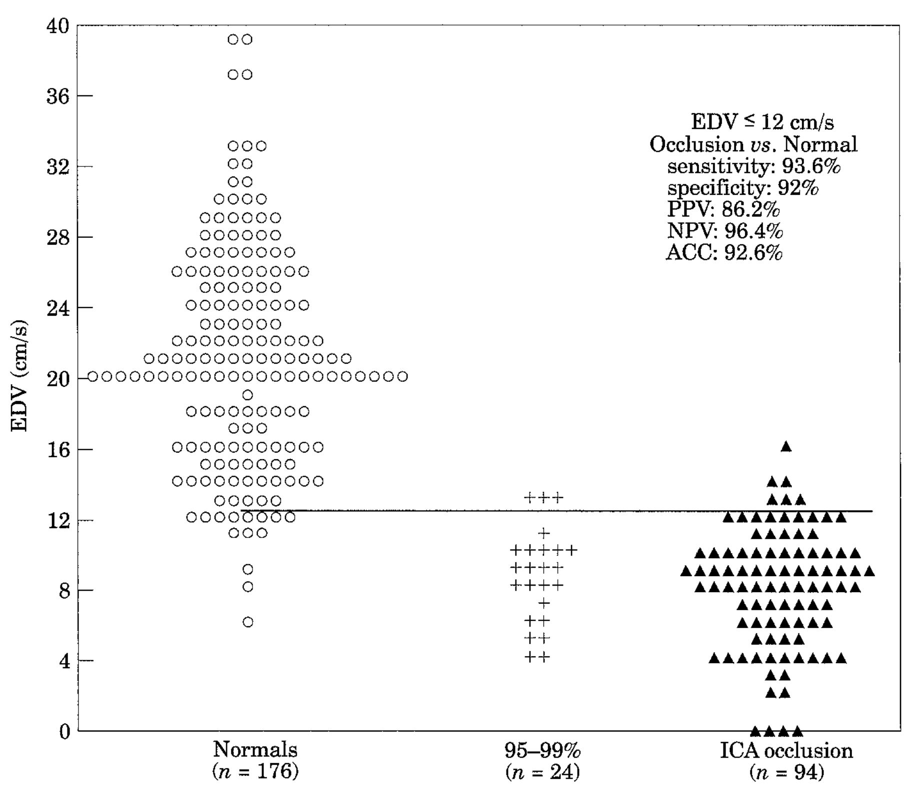

Fig. 1. Scattergram showing the best cut off value for the ipsilateral common carotid artery EDV in the retrospective study.

Figure 2 presents the distribution of DIFF in the three groups. DIFF ≥ 10cm/s defined best those with ICA occlusion from the normal group, as it produced a minimum of four FP and 11 FN results. Again, this parameter could not distinguish between total and near total ICA occlusion.

Figure 3 illustrates EDV against DIFF for the three groups, presenting the effect of the combination of EDV ≤ 12cm/s plus DIFF ≥ 10cm/s. Only one FP and one FN tests were produced by these limits. More so, all testing parameters describing the accuracy of this combination of CCA end-diastolic velocity variables to define normals from patients with ICA occlusion were superior to those of the lone EDV values (sensitivity 98.9%, specificity 99.4%, PPV 98.9%, NPV 99.4%, accuracy 99.3%).

Prospective evaluation

Table 2 presents the distribution of CCA end-diastolic velocity variables in all 802 patients who were evaluated by CFDI during 1994 against different grades of ICA stenosis. One hundred fifty-nine patients had EDV ≤ 12cm/s (20%), 83 patients had DIFF ≥ 10cm/s (10.3%) and 60 had both EDV ≤ 12 and DIFF ≥ 10 (7.5%). It is obvious that the more severe the ICA disease the higher the percentage of patients who have low EDV characteristics, i.e. EDV ≤ 12 and/or DIFF ≥ 10. Conversely, the percentage of patients with EDV > 12 and DIFF < 10 was constantly diminishing with the increase of ICA diameter stenosis.

Of patients with EDV ≤ 12cm/s, 47 (29.5%) had ICA occlusion, 13 (8.2%) had 95–99% ICA stenosis, and 49 (30.8%) had 0–15% ICA disease. That is, only one out of three examined patients having EDV ≤ 12 had 95–99% ICA stenosis or ICA occlusion (60/159, 37.7%) and another third had minimal or no disease at all. On the other hand, of 643 patients with EDV > 12cm/s, four (0.6%) had total and three (0.5%) subtotal ICA occlusion. That is, only 1% of patients with EDV > 12 had greater than 95% ICA stenosis.

Of patients with DIFF ≥ 10cm/s, 43 (51.9%) had occlusion and 9 (10.8%) 95–99% ICA stenosis. In that group, about two thirds of patients with DIFF ≥ 10 had subtotal or total ICA occlusion. EDV asymmetry was uncommon in patients with less than 95% ICA stenosis (31/735, 4.2%).

Of patients with both EDV ≤ 12 and DIFF ≥ 10, 48 (80%) had either 95–99% ICA stenosis or occlusion and 3 (5%) minimal or no disease. On the other hand, of 620 patients with both EDV > 12 and DIFF < 10 only 3 (0.5%) had 95–99% ICA stenosis or occlusion.

Table 2 also indicates the number of patients with EDV to zero in the CCA ipsilateral to the most affected

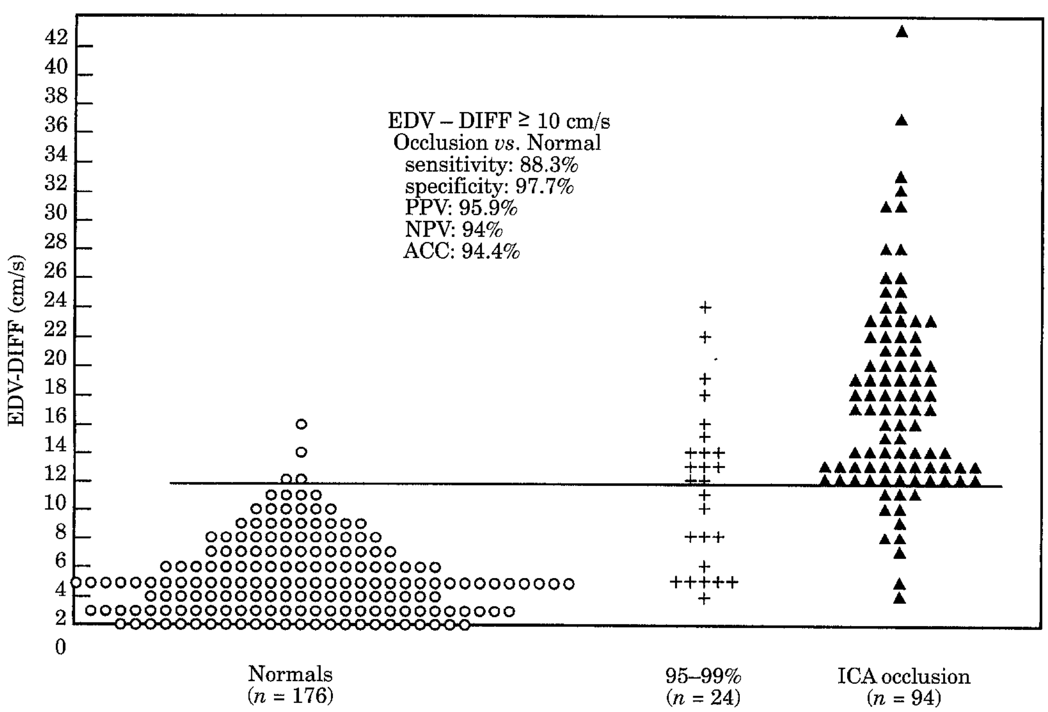

Fig. 2. Scattergram showing the best cut off value for the EDV difference between the two common carotid arteries in the retrospective study.

ICA. EDV to zero was a rare finding as its prevalence was 2% in our study (16 patients). Only eight of them had ICA occlusion.

Table 3 shows the test characteristics for all three EDV parameters in the distinction of patients with total ICA occlusion from those without occlusion. The most sensitive of all parameters was EDV ≤ 12 alone (sensitivity 92.2%), which also had the highest negative predictive value (99.4%). The most specific parameter was the combination of EDV ≤ 12 and EDV-DIFF ≥ 10 (97.5%) which also had the best overall accuracy (96.4%), but at the same time the lowest sensitivity (80.4%). The positive predictive value (PPV) was low for all parameters, at a 6.4% prevalence of total ICA occlusion in the studied population.

Regarding the distinction between 95–99% ICA stenosis and ICA occlusion, the positive predictive value of EDV ≤ 12 alone was 78.3%, of DIFF ≥ 10 alone was 82.7% and of both EDV ≤ 12 and DIFF ≥ 10 was 85.5 (Table 4).

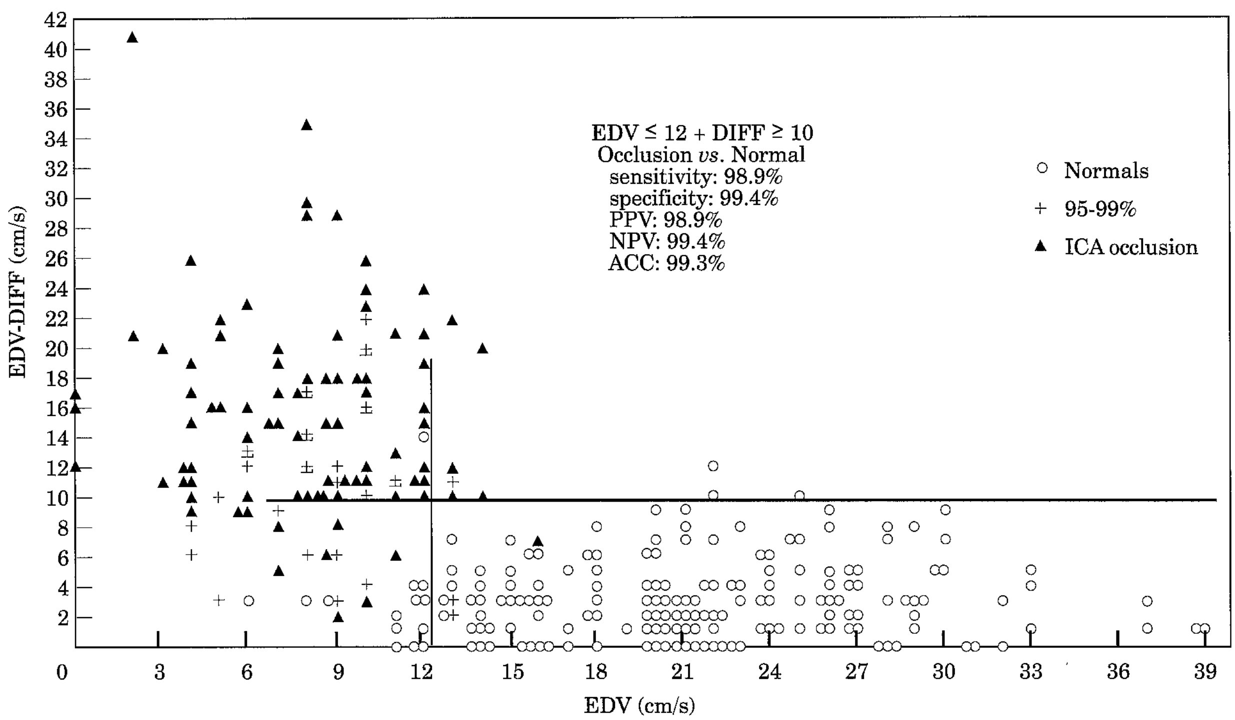

Fig. 3. Scattergram showing the best cut off value for the ipsilateral common carotid artery EDV against the EDV difference between the two common carotid arteries in the retrospective study.

Table 2. Prevalence of different EDV variables in each grade of ICA stenosis in 802 prospective study patients

Grade of ICA stenosis	EDV≤12 cm/s	DIFF≥10 cm/s	EDV≤12 cm/s and DIFF≥10 cm/s	EDV>12 cm/s and DIFF<10 cm/s	EDV=0 or 1 cm/s
0–15% (*n*=520)	49 (9.4%)	7 (1.3%)	3 (0.6%)	467 (89.8%)	5
16–70% (*n*=119)	18 (15.1%)	7 (5.9%)	2 (1.7%)	96 (80.7%)	0
71–90% (*n*=72)	22 (30.6%)	8 (11.1%)	2 (2.8%)	44 (61.1%)	0
-unilateral	12	5	1	30	
-bilateral	10	3	1	14	
91–95% (*n*=24)	10 (41.7%)	9 (37.5%)	5 (20.9%)	10 (41.7%)	1
-unilateral	7	6	4	8	
-bilateral	3	3	1	2	
95–99% (*n*=16)	13 (81.3%)	9 (56.3%)	7 (43.8%)	1 (6.3%)	2
-unilateral	12	9	7	1	
-bilateral	1	0	0	0	
100% (*n*=51)	47 (92.2%)	43 (84.3%)	41 (80.4%)	2 (3.9%)	8
-unilateral	46	43	41	1	
-bilateral	1	0	0	1	
All (*n*=802)	159 (20%)	83 (10.3%)	60 (7.5%)	620 (83.9%)	16 (2%)

Table 3. Test characteristics of CCA velocity variables in the distinction between patients with ICA occlusion from those without occlusion, as assessed by CFDI (Prevalence of ICA occlusion : 6.36%)

	No occlusion	ICA occlusion	Total
EDV			
EDV>12	639	4	643
EDV≤12	112	47	159
Total	751	51	802
Sensitivity 92.2%, specificity 85.1%, PPV 29.6%, NPV 99.4%, accuracy 85.5%			
DIFF			
DIFF<10	711	8	719
DIFF≥10	40	43	83
Total	751	51	802
Sensitivity 84.3%, specificity 94.7%, PPV 51.8%, NPV 98.9%, accuracy 94%			
EDV and DIFF			
EDV>12 and DIFF<10	732	10	742
EDV≤12 and DIFF≥10	19	41	60
Total	751	51	802
Sensitivity 80.4%, specificity 97.5%, PPV 68.3%, NPV 98.6%, accuracy 96.4%			

Discussion

The most reliable ultrasonic criterion in the presence of ICA occlusion is the absence of flow within the vessel by spectral and colour Doppler.[11–13] Flow to zero or marked decrease in relative ipsilateral CCA diastolic flow in comparison with the opposite carotid has been proposed as a highly significant indicator of a very tight ICA or occlusion, either at the bifurcation or at a higher level in the neck or within the cranium.[11,14–17] "Externalisation" of the CCA flow has also been reported in young patients ≤ 40 years and in a few older persons[5]; in hypertension, tachycardia, diminished arterial compliance, diffuse peripheral disease, low cardiac output[11]; and in patients with aortic valve insufficiency, with flow reversal during late systole.[19] In these latter cases, flow to zero was commonly a bilateral finding, not related to carotid bulb disease.

Table 4. The Positive Predictive Values of EDV variables in the distinction between 95–99% ICA stenosis and ICA occlusion

	95–99%	Occlusion	Total
EDV			
EDV>12	3	3	6
EDV≤12	13	47	60
Total	16	50	66
PPV 47/60 (78.3%)			
DIFF			
DIFF<10	7	8	15
DIFF≥10	9	43	52
Total	16	51	67
PPV 43/52 (82.7%)			
EDV and DIFF			
EDV>12 and DIFF<10	1	2	3
EDV≤12 and DIFF≥10	7	41	48
Total	8	43	51
PPV 41/48 (85.4%)			

This study aimed to quantify EDV parameters and investigate their distribution among patients referred to our laboratory, with the aid of recent scanners capable of detecting flow velocities as low as 0.3 cm/sec. Thus, retrospective analysis of CCA-EDV data in patients with angiographically confirmed ICA occlusion and in normal individuals revealed that EDV ≤ 12cm/s or DIFF ≥ 10cm/s were very accurate in identifying patients with total ICA occlusion. Furthermore, when combined, were almost ideal in this distinction (all indices higher than 98%, 99.3% overall accuracy).

Tested prospectively, EDV ≤ 12cm/s alone had a considerable 92% sensitivity in the distinction of patients with ICA occlusion from those without, but at the expense of specificity (85%). Actually, one third of patients with EDV ≤ 12 had minimal or no ICA disease at all (49/159, 31%). Evaluation of the hospital notes of these 49 patients showed that four of them had a silent CT brain infarct, 18 had suffered a stroke, seven had cardiac ejection fraction lower than 30% and four had atrial fibrillation. In addition, DIFF ≥ 10 was very rare in patients with 0–15% stenosis (7/520, 1.4%). All but one of these seven "normals" had a history of stroke. Thus, it seems possible that low or/and asymmetric EDV in patients with normal cervical carotid vessels may be related to altered haemodynamics at a higher level. Patients with CT brain infarcts or history of stroke appear to form another category of patients with such CCA diastolic flow characteristics, especially with EDV asymmetry. EDV ≤ 12, but especially EDV asymmetry, are more common in patients with unilateral ICA stenosis, particularly in those with significant disease. This seems to be in accordance with what has been stated in the literature regarding CCA flow waveform changes related with much higher resistance ipsilaterally to the most severe ICA stenosis.

EDV ≤ 12 had only 78% PPV in the distinction of patients with subtotal from those with total ICA occlusion whereas the combination of EDV ≤ 12cm/s and DIFF ≥ 10cm/s had 85.4%, the highest of EDV parameters in this distinction. These figures, however, remain unacceptable, remembering that such a distinction is clinically absolutely crucial. Thus, they do not add any worthwhile information to the CFDI examination of patients having severely diseased ICA's. However, the high negative predictive value of EDV ≤ 12 (99.4%) may indicate that it can be used as a simple screen sign to exclude total ICA occlusion. The combination of EDV ≤ 12cm/s and EDV-DIFF ≥ 10cm/s was the most accurate and the most specific between

EDV variables in distinguishing patients having ICA occlusion from those who had not, but with the lowest sensitivity and NPV. Thus, symmetric EDV > 12cm/s may be useful for the exclusion of ICA occlusion. Zwiebel has stated that the asymmetric waveform abnormality associated with ICA obstruction may be detected visually without the need of pulsatility measurements.[11] We believe DIFF ≥ 10 to be a more precise indicator.

Breslau *et al.* reported 93% incidence of flow to zero in patients with ICA occlusion,[17] however we have found that flow only rarely went to zero and only 38% of patients with ICA occlusion had EDV less than 6cm/s. This discrepancy could be explained by the fact that the older scanners they were using, might not have been sensitive enough to detect small velocity ranges.

A limitation of the study was that ICA stenoses were graded by CFDI criteria only, in the prospective study. However, CFDI has been widely used in the evaluation of carotid bifurcation disease. In addition, previous studies from our laboratory have compared ultrasonic and arteriographic findings and validated the criteria we have used.[18] More so, 46 patients with a CFDI diagnosis of 95–99% ICA stenosis or occlusion, were also subjected to IA DSA within 15 days from the CFDI during 1994. Analysis of these data revealed that the positive predictive value of CFDI to diagnose total ICA occlusion was 97.4% during 1994 (unpublished data). Reproducibility studies for velocity measurements also did not take place, as our aim was to evaluate velocities during routine carotid scanning.

In conclusion, common carotid artery EDV ≤ 12cm/s alone is a sensitive marker of ICA occlusion with high NPV, and in combination with DIFF ≥ 10cm/s is highly specific for occlusion. However, EDV parameters are clinically suboptimal in the distinction between 95–99% ICA stenosis from ICA occlusion. Low and/or asymmetric EDV can also be found in a significant number of patients with minor or no ICA disease, and this may be due to a cerebrovascular accident or a silent brain infarct in many of these patients.

References

1 Blackshear WM, Connar RG. Carotid endarterectomy without angiography. *J Cardiovasc Surg* 1982; **23**: 477.

2 Thomas GI, Jones TW, Stanvey LS, Manhas DR, Spencer MP. Carotid endarterectomy after Doppler ultrasonographic examination without angiography. *Am J Surg* 1986; **151**: 616–619.

3 Wagner WH, Treiman RL, Cossman DV, Foran RF, Levin PM, Cohen JL. The diminishing role of diagnostic arteriography in carotid artery disease: Duplex scanning as definitive preoperative study. *Ann Vasc Surg* 1991; **5**: 105–110.

4 Dawson DL, Zierler RE, Strandness Jr DE, Clowes AW, Kohler TR. The role of Duplex scanning and arteriography before carotid endarterectomy: a prospective study. *J Vasc Surg* 1993; **18**: 673–683.

5 Jacobs NM, Grant EG, Schellinger D, Byrd CM, Richardson JD, Cohan SL. Duplex carotid sonography: criteria for stenosis, accuracy, and pitfalls. *Radiology* 1985; **154**: 385–391.

6 Erickson SJ, Mewissen MW, Foley DW *et al.* Stenosis of the internal carotid artery: assessment using colour Doppler imaging compared with angiography. *AJR* 1989; **152**: 1299–1305.

7 Steinke W, Kloetzsch C, Hennerici M. Carotid artery disease assessed by colour Doppler flow imaging. Correlation with standard Doppler sonography and arteriography. *AJR* 1990; **154**: 1061–1068.

8 Ferguson GG. Extracranial carotid artery surgery. *Clin Neurosurg* 1982; **29**: 543–574.

9 Mattos MA, Hodgson KJ, Ramsey DE, Barkmeier LD, Sumner DS. Identifying total carotid occlusion with colour flow duplex scanning. *Eur J Vasc Surg* 1992; **6**: 204–210.

10 Londrey GL, Spadone DP, Hodgson KJ, Ramsey DE, Barkmeier LD, Sumner DS. Does colour-flow imaging improve the accuracy of duplex carotid evaluation? *J Vasc Surg* 1991;**13**: 659–662.

11 Zwiebel WJ. Colour-Duplex features of normal and abnormal carotid arteries - Doppler evaluation of carotid stenosis. In: Zwiebel WJ, Ed. *Introduction to vascular ultrsonography.* 3rd edition, Philadelphia: WB Saunders Co, 1992: 105–131.

12 Sumner DS. Is colour coded Doppler a waste of money? In: Bernstein EF, Ed. *Vascular diagnosis.* 4th edition. St. Louis: Mosby, 1993: 125–132.

13 Zierler RE. Real-time colour flow Doppler carotid imaging. In: Bernstein EF, Ed. *Vascular diagnosis.* 4th edition. St. Louis: Mosby, 1993: 328–332.

14 Planiol T, Pourcelot L. Doppler effect study of the carotid circulation (Etude de la circulation carotidienne au moyen de l'effect Doppler). Traites de Radio-diagnostique. Masson, Paris 1971, Vol. 17.

15 Bodily KC, Phillips DJ, Thiele BL, Strandness DE Jr. Noninvasive detection of internal carotid artery occlusion. *Angiology* 1981; **32**: 517–521.

16 Fell G, Phillips DJ, Chikos PM, Harley JD, Thiele BL, Strandness DS Jr. Ultrasonic duplex scanning for disease of the carotid artery *Circulation* 1981; **64**: 1191–1195.

17 Breslau PJ, Fell G, Phillips DJ, Thiele BL, Strandness DE Jr. Evaluation of carotid bifurcation disease. The role of common carotid artery velocity patterns. *Arch Surg* 1982;**117**: 58–60.

18 Williams MA, Deacon DFS, Szendro G, Belcaro G, Nicolaides AN. Duplex scanning in the detection and grading of ICA stenosis: improved criteria. In: AN Nicolaides, Salmasi AM Eds. *Cardiovascular applications of Doppler ultrasound.* London: Churchill-Livingstone, 1989: 247–260.

19 Rittenhouse EA, Strandness DE Jr. Oscillation flow patterns in patients with aortic valve disease. *Am J Cardiol* 1971; **28**: 568–574.

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